5G mmWave Developer Kit
Labsheet Part I

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Part I	Lab 1. What is the link budget? Lab 2. What is channel gain?
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⚠ Please peruse the User Guide before using the developer kit.

Introduction

The 5G (5th generation mobile network) continues to be popular in 2022. With countries releasing new licenses for the FR2 frequency band one after another, operators also bid fiercely for their target bands. The FR2 frequency band includes n258(24.25-27.5 GHz), n257(26.5-29.5 GHz), n260(37-40 GHz), and n261(27.5-28.35 GHz). The FR2 is different from FR1, it can provide wider data bandwidth to satisfy high throughput and low latency features. However, it has a weakness, and it is the short wavelength that may contribute to higher path loss. To overcome this weakness, beamforming is the key technology to solve the mmWave application. In fact, beamforming has already been adopted in many applications such as FWA, Low Earth Orbit (LEO) Satellite, ADAS, ADAS, and more.

The mmWave development is an inevitable trend in the coming years and the market size will explode in growth. The mission is obvious, to develop and train talents. For the development of mmWave, the next generation of engineers will play a key role, and it is essential that engineering graduates are prepared for the principle, practice, and advanced research of related mmWave technologies. But, the reality is that the cost of mmWave relevant components is very expensive and difficult to demonstrate practical operating applications. The TMYTEK Developer Kit is a complete and affordable mmWave training tool for lecturers, professors, and researchers. It provides complete mmWave components as well as ready-made practical classes. It is not only a great entry-level kit for mmWave teaching, but also extends to advanced research with other options like Software Defined Radio (SDR), Arduino, and Up/Down Converter.

What's included

- 5G FR2 Beamformer - BBoard ×1
- Signal Soure - PLO ×1
- Power Detector ×1
- 5G FR2 Array Antenna ×1
- 28 GHz COCO Antenna ×1
- 20 GHz-40 GHz Amplifier ×1
- 40 GHz RF Cable ×4
- 10 GHz-40 GHz Combiner/Splitter ×1

BBoard
n257 beamformer.

Signal Source PLO
26.5-29.5 GHz. 8 steps.

Power Detector
0.1-40 GHz.
35 dB Dynamic Range.

Array Antenna
n257. 15 dBi gain.

COCO Antenna
27-29 GHz. 7 dBi gain.

Amplifier
20-40 GHz. 15 dB gain.

RF Cables
Up to 40 GHz.

Power Combiner/Splitter
10-40 GHz. 1.2 dB loss.

Figure 1. List of Developer Kit

Lab 1 - What is the link budget?

1. Significance

The link budget is the term used to evaluate the received power at the receiver. It points out all gains and losses from transmitter to receiver. It includes the losses from connectors, cables, and other RF components in the communication chain, gains provided by antenna, amplifier, propagation loss, etc. The link budget is an important parameter, it can help engineers evaluate and design the communication system under the target distance according to the receiver sensitivity. The sensitivity is an important indicator for a communication receiver which means how low a signal can be captured. In other words, the sensitivity will affect the wireless communication distance directly.

2. Aim

Calculating the link budget is a fundamental and essential requirement for wireless communication. Engineers must know how to evaluate the link budget to build an excellent wireless communication system over the expected distance. The following equation and diagram represent the link budget.

$$Received\ Power(dBm) = Transmitted\ Power(dBm) + gains(dB) - losses(dB)$$
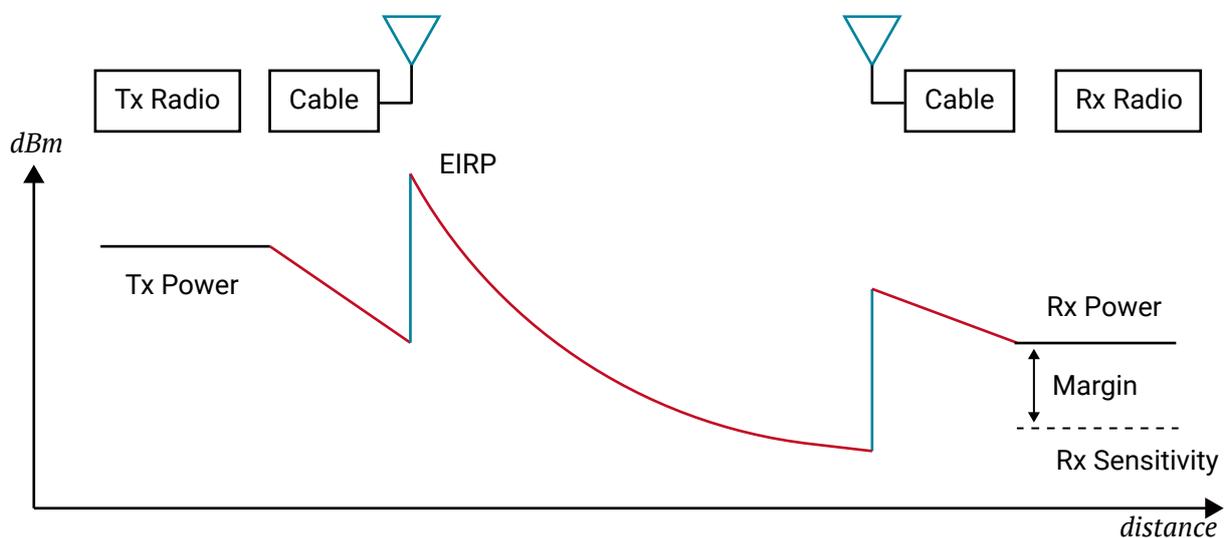

Figure 2. Link Budget Overview

To build the link budget, You must know the gains and losses of all components and free space path loss under the communication link. You can calculate the path loss using the below equation, where d is distance, λ is wavelength, f is operating frequency, and c is speed of light. So, You just need to confirm the gains and losses of RF components from the Developer Kit.

$$FSPL(dB){=}20 \times log_{10}(\frac{4\pi d}{\lambda}){=}20 \times log_{10}(\frac{4\pi df}{c})$$

3. Requirements

- 5G FR2 Beamformer - BBoard ×1
- Signal Soure - PLO ×1
- Power Detector ×1
- 5G FR2 Array Antenna ×1
- 28 GHz COCO Antenna ×1
- 20 GHz-40 GHz Amplifier ×1
- 40 GHz RF Cable ×4
- 10 GHz-40 GHz Combiner/Splitter ×1
- A personal computer with TMXLAB kit and LTC5596 GUI installed
- DC power supply

4. Procedure

a. Install the attenuator at the output end of the PLO and connect to the power detector through 2.92mm to 2.92mm adapter. Monitor and record the power readout from the LTC5596 GUI.
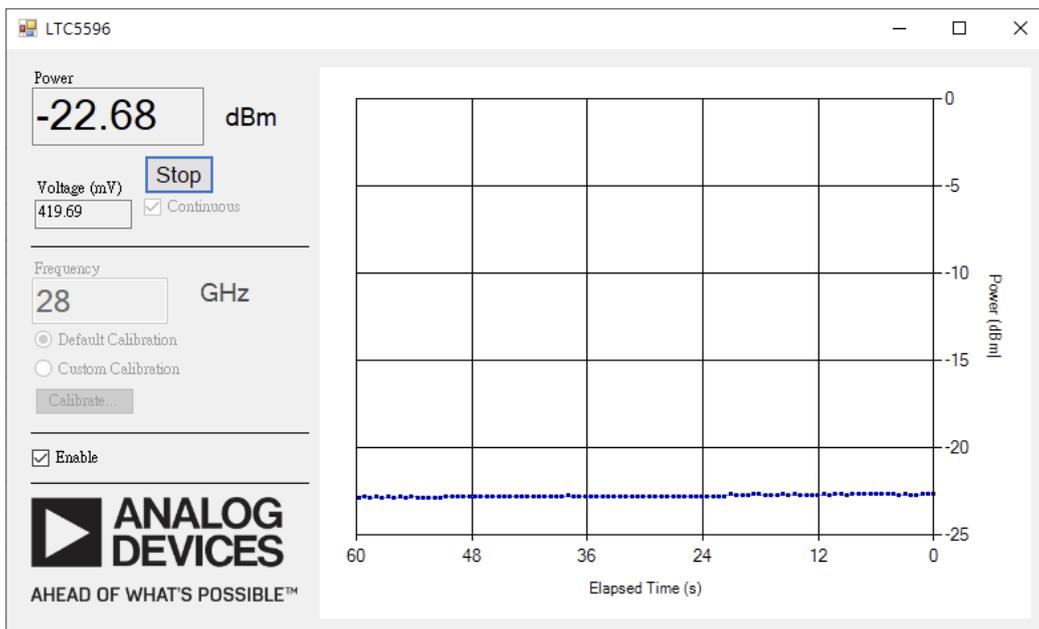

Figure 3. PLO + Attenuator + Adapter

Figure 4. Measured power of PLO + Attenuator + Adapter

b. Replace the 2.92mm to 2.92mm adapter with the four 40GHz RF cables provided. Connect one at a time, monitor and record the power readout.
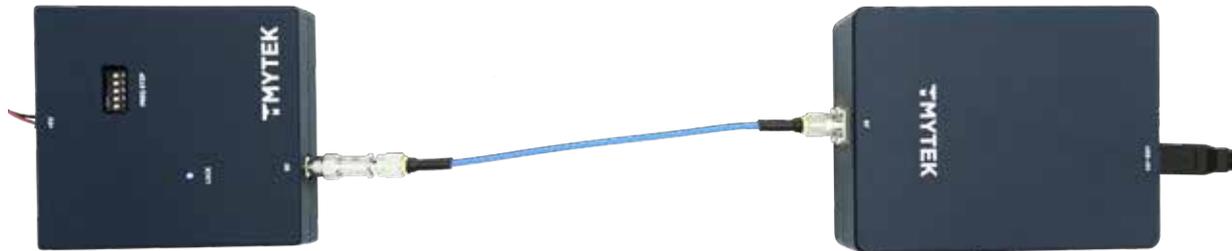

Figure 5. PLO + Attenuator + Cable

c. Place the power splitter between the attenuator and the cable. The 2.92 mm to 2.92 mm adapter is required to connect the attenuator to the combiner port as shown in Figure 6. Then, monitor and record the power readout. As the power splitter is a 1:2 power splitter, you will need to unplug and replug the cable into the other port to monitor and record the readout as well.
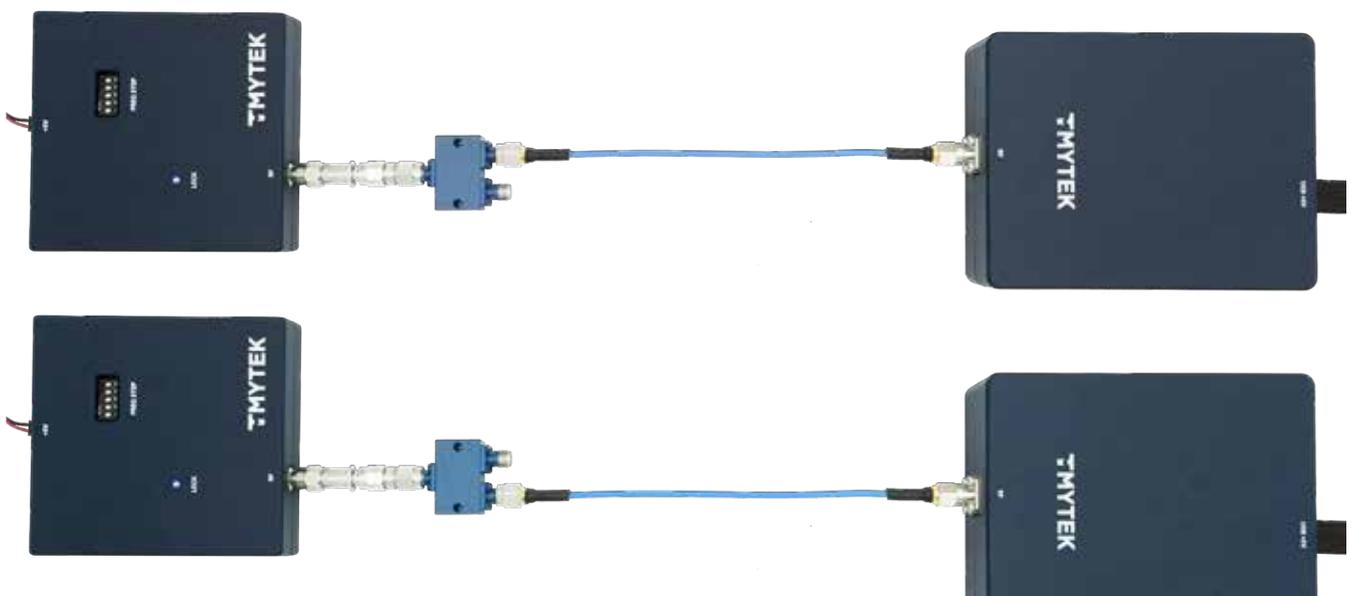

Figure 6. PLO + Attenuator + Adapter + Power Splitter + Cable

d. Reverse the power splitter into a power combiner, monitor and record the power readout as shown in Figure 7. Same as above, you need to unplug and replug the cable into the other port to monitor and record the readout as well.
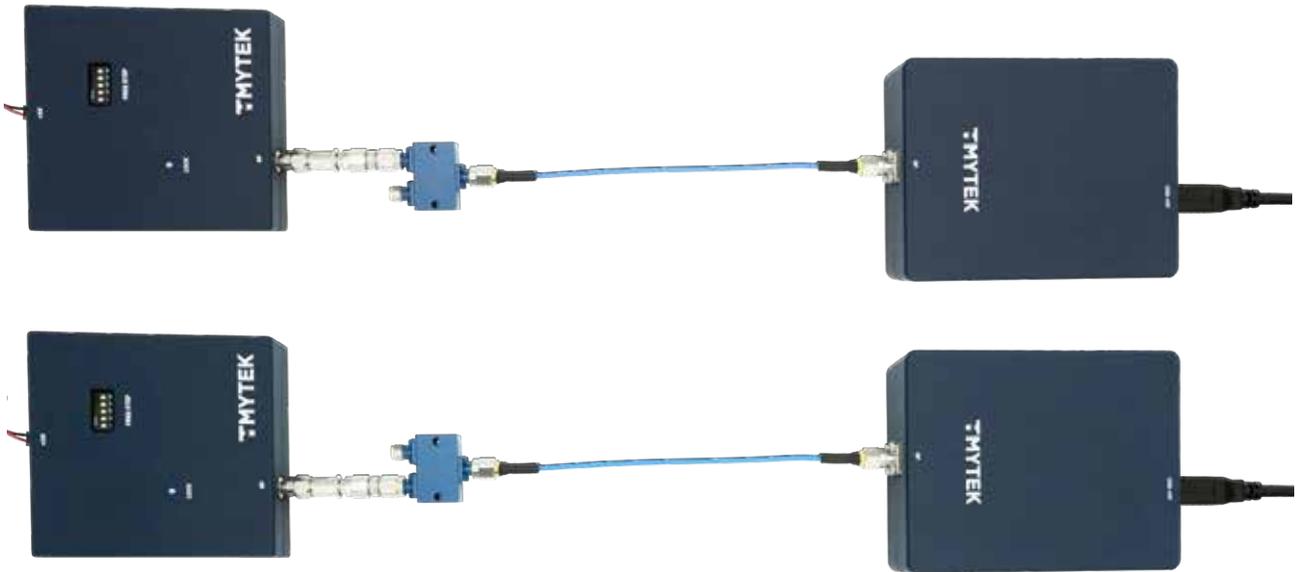

Figure 7. PLO + Attenuator + Adapter + Power Combiner + Cable

e. Replace the power combiner with the amplifier, monitor and record the power readout. You need to provide a +12V DC for the amplifier.

Figure 8. PLO + Attenuator + Adapter + Amplifier + Cable

5. Results

The test results are only for reference; they may differ depending on the developer kit or the conditions.

Table 1 is the test result you measured. To get the individual gain and loss, we must have a known value and introduce it in table 1. According to the test report of the adapter, the insertion loss is about -0.28 dB, refer to Figure 9, so you can get the gain or loss of relevant components from your monitoring result in Table 2. For the following lab exercises, you can use these parameters to calculate the link budget with different setups.

Configuration	Power Readout (dBm)
PLO + Attenoutor + Adapter	-22.68
PLO + Attenoutor + Cable #1	-22.85
PLO + Attenoutor + Cable #2	-22.85
PLO + Attenoutor + Cable #3	-22.84
PLO + Attenoutor + Cable #4	-22.85
PLO + Attenoutor + Adapter + Power splitter (Right) + Cable #1	-22.87
PLO + Attenoutor + Adapter + Power splitter (left) + Cable #1	-27.86
PLO + Attenoutor + Adapter + Power combiner (Right) + Cable #1	-27.21
PLO + Attenoutor + Adapter + Power combiner (left) + Cable #1	-27.20
PLO + Attenoutor + Adapter + Amplifier + Cable #1	-2.88

Table 1. Power Readout in different configurations

Figure 9. S-Parameter of the Adapter

Component	Gain / Loss (dB)
Adapter (Assume)	-0.28
PLO + Attenoutor	-22.40
Cable#1	-0.45
Cable#2	-0.45
Cable#3	-0.44
Cable#4	-0.45
Power splitter_Right side	-4.74
Power splitter_Left side	-4.73
Power combiner_Right side	-4.08
Power combiner_Left side	-4.07
Amplifier	20.25

Table 2. Gain or Loss for each component

Lab 2 - What is channel gain?

1. Significance

Beamforming is a signal processing technique used in channel arrays for directional signal transmission or reception. The beamformer, BBoard, mainly consists of amplifiers and phase shifters. Controlling the channel power and phase to change the pattern and direction of the beam. To perform beam pattern shaping, you must be able to adjust precisely the gain among all channels.

2. Aim

In the experiment, you will find out how to measure each RF channel's gain, how to adjust them , and what is the difference between each gain state. After understanding the linearity of each channel gain and the difference among them, then you can try to calibrate it if needed.

3. Requirements

- 5G FR2 Beamformer - BBoard ×1
- Signal Soure - PLO ×1
- Power Detector ×1
- 40 GHz RF Cable ×2
- 10 GHz-40 GHz Combiner/Splitter ×1
- A personal computer with TMXLAB kit and LTC5596 GUI installed

4. Procedure

a. Utilizing the PLO and adding an attenuator as the source, and connecting it to BBoard's RF com port by an RF cable.

b. Connect one of the BBoard's RF channels to the power detector by an RF cable.

Figure 10. Configuration of Lab 2

c. Adjust the TMXLAB kit for gain states. There are two attenuators that can be adjusted in the TMXLAB kit, one is the common attenuator and another is the channel attenuator. It is 1 dB per step for the common attenuator and 0.5 dB per step for the channel attenuator.
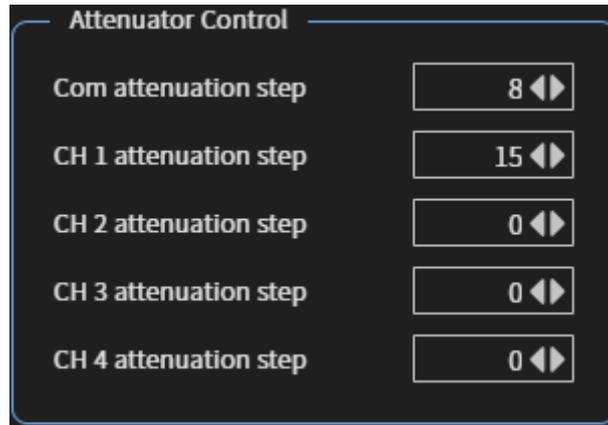

Figure 11. Attenuator Control of TMXLAB Kit

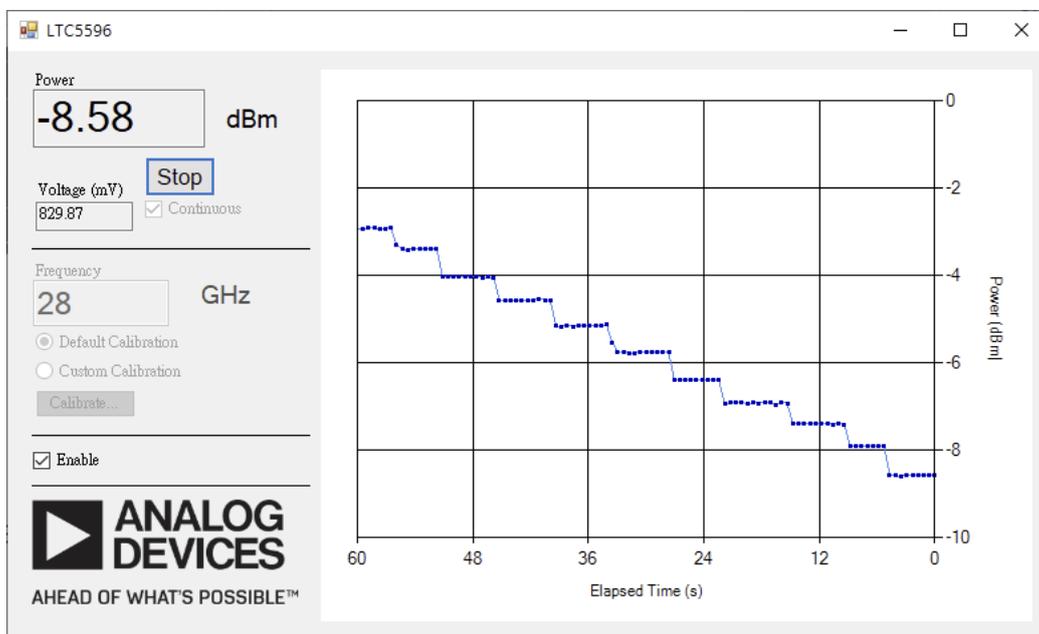d. Observe and record the detected power on the LTC5596 GUI after adjusting the gain state.

Figure 12. Measured Power from LTC5596

e. Repeat steps a to d on all four BBoard RF channels.

5. Results

The test results are only for reference; they may differ depending on the developer kit or the conditions.

| Attenuator Step		Expected Attenuation	Power Readout				Differences		
Common	Channel		Channel 1	Channel 2	Channel 3	Channel 4	1 & 2	1 & 3	1 & 4
0	0	0.00	-6.90	-7.07	-7.42	-5.06	-0.17	-0.52	1.84
0	1	0.50	-7.42	-7.57	-7.91	-5.65	-0.15	-0.49	1.77
0	2	1.00	-7.91	-8.08	-8.41	-6.21	-0.17	-0.50	1.70
0	3	1.50	-8.57	-8.62	-8.92	-6.73	-0.05	-0.35	1.84
0	4	2.00	-9.09	-9.25	-9.58	-7.24	-0.16	-0.49	1.85
0	5	2.50	-9.59	-9.76	-10.07	-7.74	-0.17	-0.48	1.85
0	6	3.00	-10.09	-10.26	-10.47	-8.25	-0.17	-0.38	1.84
0	7	3.50	-10.42	-10.60	-10.93	-8.68	-0.18	-0.51	1.74
0	8	4.00	-10.76	-11.06	-11.27	-9.07	-0.30	-0.51	1.69
0	9	4.50	-11.38	-11.58	-11.77	-9.58	-0.20	-0.39	1.80
0	10	5.00	-11.89	-12.10	-12.27	-10.09	-0.21	-0.38	1.80
0	11	5.50	-12.44	-12.62	-12.94	-10.63	-0.18	-0.50	1.81
0	12	6.00	-12.99	-13.14	-13.45	-11.26	-0.15	-0.46	1.73
0	13	6.50	-13.62	-13.78	-14.04	-11.83	-0.16	-0.42	1.79
0	14	7.00	-14.20	-14.29	-14.62	-12.44	-0.09	-0.42	1.76
0	15	7.50	-14.62	-14.79	-15.12	-12.93	-0.17	-0.50	1.69
1	15	8.50	-15.80	-15.97	-16.29	-14.12	-0.17	-0.49	1.68
2	15	9.50	-16.96	-17.13	-17.44	-15.17	-0.17	-0.48	1.79
3	15	10.50	-17.81	-17.97	-18.31	-16.10	-0.16	-0.50	1.71
4	15	11.50	-19.15	-19.32	-19.65	-17.46	-0.17	-0.50	1.69
5	15	12.50	-19.65	-19.80	-20.06	-17.82	-0.15	-0.41	1.83
6	15	13.50	-20.55	-20.66	-20.99	-18.82	-0.11	-0.44	1.73
7	15	14.50	-21.32	-21.35	-21.62	-19.49	-0.03	-0.30	1.83
8	15	15.50	-22.32	-22.37	-22.62	-20.50	-0.05	-0.30	1.82
9	15	16.50	-23.51	-23.63	-23.86	-21.67	-0.12	-0.35	1.84
10	15	17.50	-24.58	-24.69	-25.02	-22.84	-0.11	-0.44	1.74
11	15	18.50	-25.52	-25.53	-25.87	-23.68	-0.01	-0.35	1.84
12	15	19.50	-26.83	-26.87	-27.20	-25.02	-0.04	-0.37	1.81
13	15	20.50	-26.82	-26.87	-27.21	-25.02	-0.05	-0.39	1.80
14	15	21.50	-26.83	-26.87	-27.20	-25.02	-0.04	-0.37	1.81
15	15	22.50	-26.82	-26.87	-27.21	-25.02	-0.05	-0.39	1.80

Table 3. Test Results
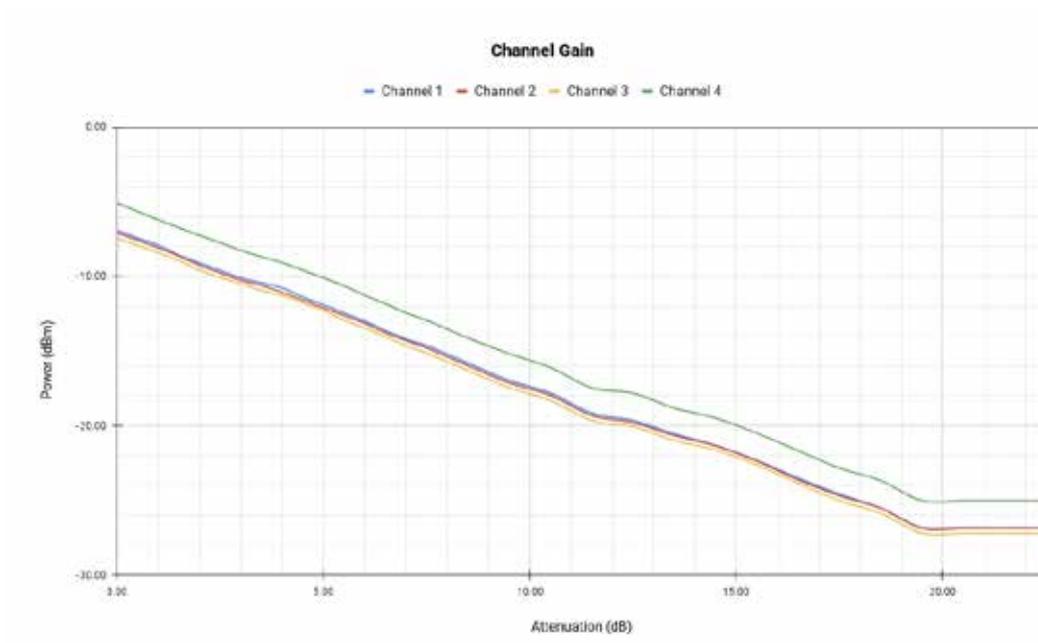
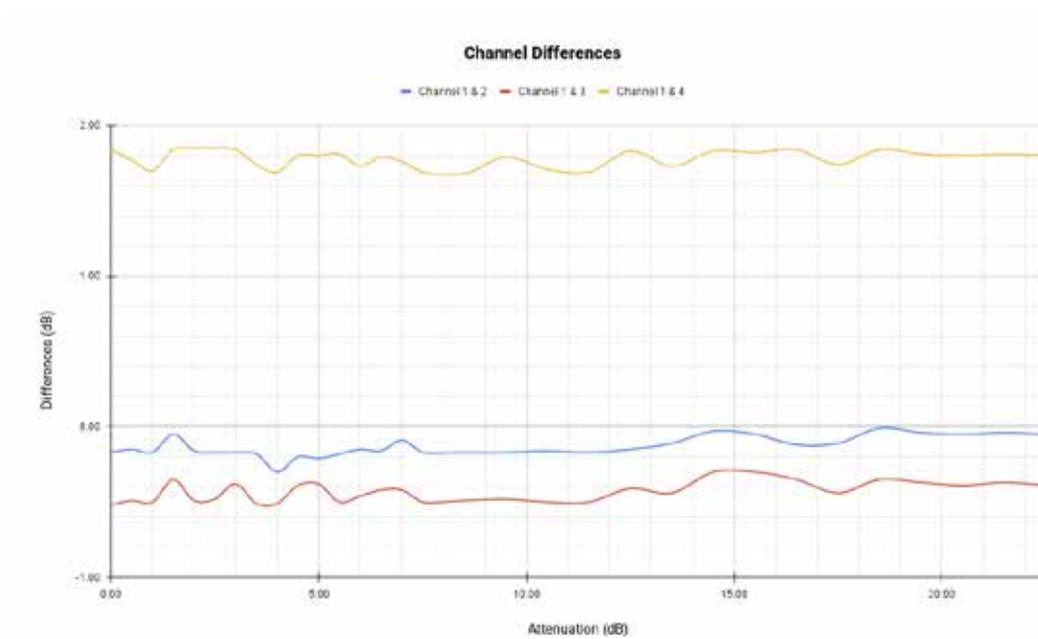Figure 13. The Performance of Attenuator among 4 RF Channels

Figure 14. The Channel Difference among 4 RF Channels
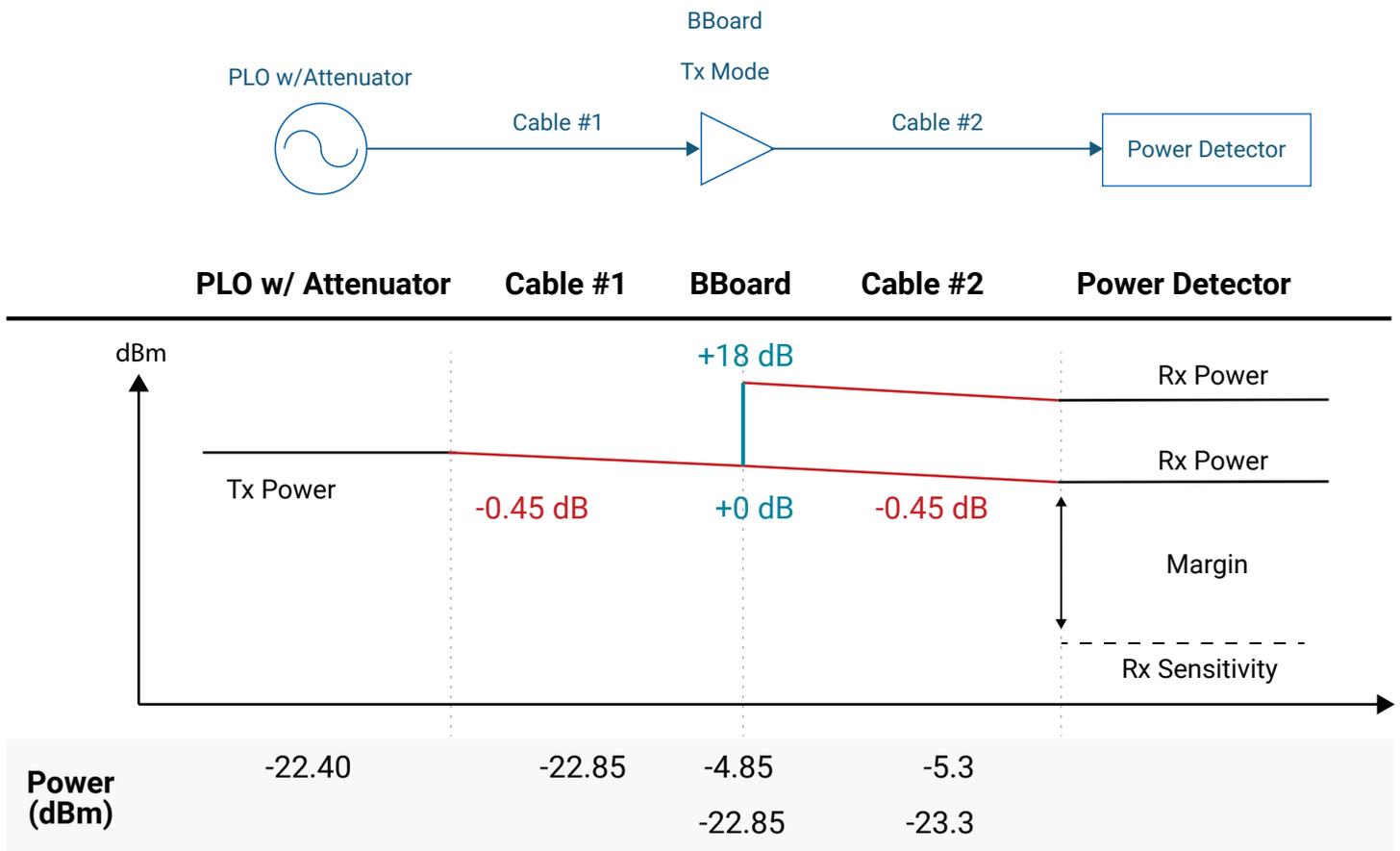
Calculate the link budget using results in Lab 1 and compare it against your results.

Figure 15. Link Budget Calculation

	PLO w/ Attenuator	Cable #1	BBoard	Cable #2	Power Detector
Power (dBm)	-22.40	-22.85	-4.85	-5.3	
			-22.85	-23.3	